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Wave Activity and Its Changes in the Troposphere and Stratosphere of the Northern Hemisphere in Winters of 1979–2016

V. V. Guryanov[a], A. V. Eliseev[a, b, *], I. I. Mokhov[b, c, d], and Yu. P. Perevedentsev[a]

[a]*Kazan Federal University, Kazan, 420008 Russia*

[b]*A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, 119017 Russia*

[c]*Lomonosov Moscow State University, Moscow, 119991 Russia*

[d]*Moscow Institute of Physics and Technology (State University), Dolgoprudny, Moscow oblast, 141700 Russia*

**e-mail: eliseev@ifaran.ru*

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Abstract—An analysis of spectra of wave disturbances with zonal wave numbers $1 \leq k \leq 10$ is carried out using winter (November to March) ERA-Interim reanalysis geopotential data in the troposphere and stratosphere for 1979–2016. Contributions of eastward-traveling (E), westward-traveling (W), and stationary (S) waves are estimated. The intensification of wave activity is observed in the tropical troposphere and stratosphere and in the upper stratosphere of the entire Northern Hemisphere. The intensification of wave activity in the tropics and subtropics is noted for waves of all types (E, W, and S), while in the middle and higher latitudes it is related mainly to stationary and eastward waves. Near the subtropical tropopause, the energy of stationary waves has increased in recent decades. In addition, in the tropical and subtropical troposphere and in the subtropical lower stratosphere, the energy of the eastward-traveling waves in El Niño years may be one and a half times or twice the energy in La Niña years. The spectrally weighted zonal wave numbers for waves of all types (E, W, and S) are the largest in the upper subtropical troposphere. The spectrally weighted zonal wave number for W and S waves is correlated with the Atlantic Multidecadal Oscillation index and varies by 15% in 1979–2016 (on an interdecadal time scale). The spectrally weighted wave period is larger in the stratosphere than in the troposphere. It is maximal in the middle extratropical stratosphere. The spectrally weighted wave periods correlate with the activity of sudden stratospheric warmings. The sign of this correlation depends on the latitude, atmospheric layer, and zonal wave number.

Keywords: atmospheric waves, troposphere, stratosphere, Hayashi spectra, climate variability, sudden stratospheric warming, El Niño–Southern Oscillation, Atlantic Multidecadal Oscillation

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1. INTRODUCTION

Atmospheric wave motions are able to transfer energy and momentum [1, 2]. First, the characteristics of these waves are determined by the state of climate; second, the wave processes may contribute to climate changes.

Rossby waves, Kelvin waves, gravity waves, and mixed Rossby–gravity waves play a key role in large-scale atmospheric dynamics [1]. Waves of all these types emerge in the tropics. At higher latitudes, a major role is played by Rossby waves, including those propagating from the troposphere into the stratosphere. This propagation is possible only for the longest waves (with zonal wave numbers k = 1–2) and only in winter, when stratospheric winds are directed from west to east and are not very strong [3]. A change in the phase of Rossby and gravity waves with height results in an eastward slope of the pressure perturbation contours. Rossby waves break in the upper stratosphere at certain critical levels of zonal wind. Gravity waves, in turn, are able to penetrate into the mesosphere.

There has been rapid climate warming in recent decades (with some slowdown in the early 21st century) [4]. This slowdown (called a hiatus) might be attributed to natural climate variations [5–10]. Consequently, characteristics of atmospheric wave processes may experience considerable variability on an interdecadal time scale and/or trend components.

Wave processes in the Earth's atmosphere have a broad spectrum of space and time scales. For analyzing these scales, space–time spectral analysis is often used [11]. This technique, in particular, was used for an analysis of the 500-hPa geopotential height from observations and numerical experiments with climate models [12–14], as well as of a number of stratospheric variables [15, 16]. There are also alternative methods of identifying waves of different types in the data fields [17–19].